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(54) **TRAFFIC ANALYSIS SYSTEM UTILIZING POSITION BASED AWARENESS**

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G08G 1/00	(2006.01)
B60W 30/08	(2012.01)
G05D 1/02	(2006.01)

(52) **U.S. Cl.**
CPC ***G01C 21/00*** (2013.01); ***B60W 30/08*** (2013.01); ***G05D 1/02*** (2013.01); ***G08G 1/22*** (2013.01)

(58) **Field of Classification Search**
CPC G08G 1/22; G01C 21/00; G60W 30/08; G05D 1/02
See application file for complete search history.

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(57) **ABSTRACT**

A system and method of analyzing traffic in a vicinity of a first machine is disclosed. The method may include determining, by one or more computer processors, a projected position of the first machine based on a yaw rate and velocity of the first machine. The method may further include determining, by the one or more computer processors, a predicted zone in the vicinity of the first machine based on the projected position of the first machine. The method may further include determining whether a second machine is present in the predicted zone. In response to determining that the second machine is present in the predicted zone, the method may further include determining whether an unsafe condition exists between the first machine and the second machine.

17 Claims, 8 Drawing Sheets
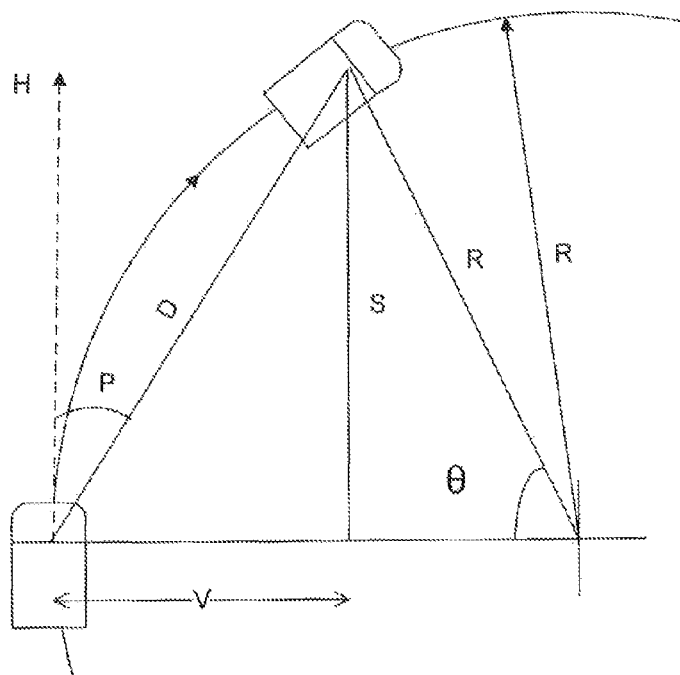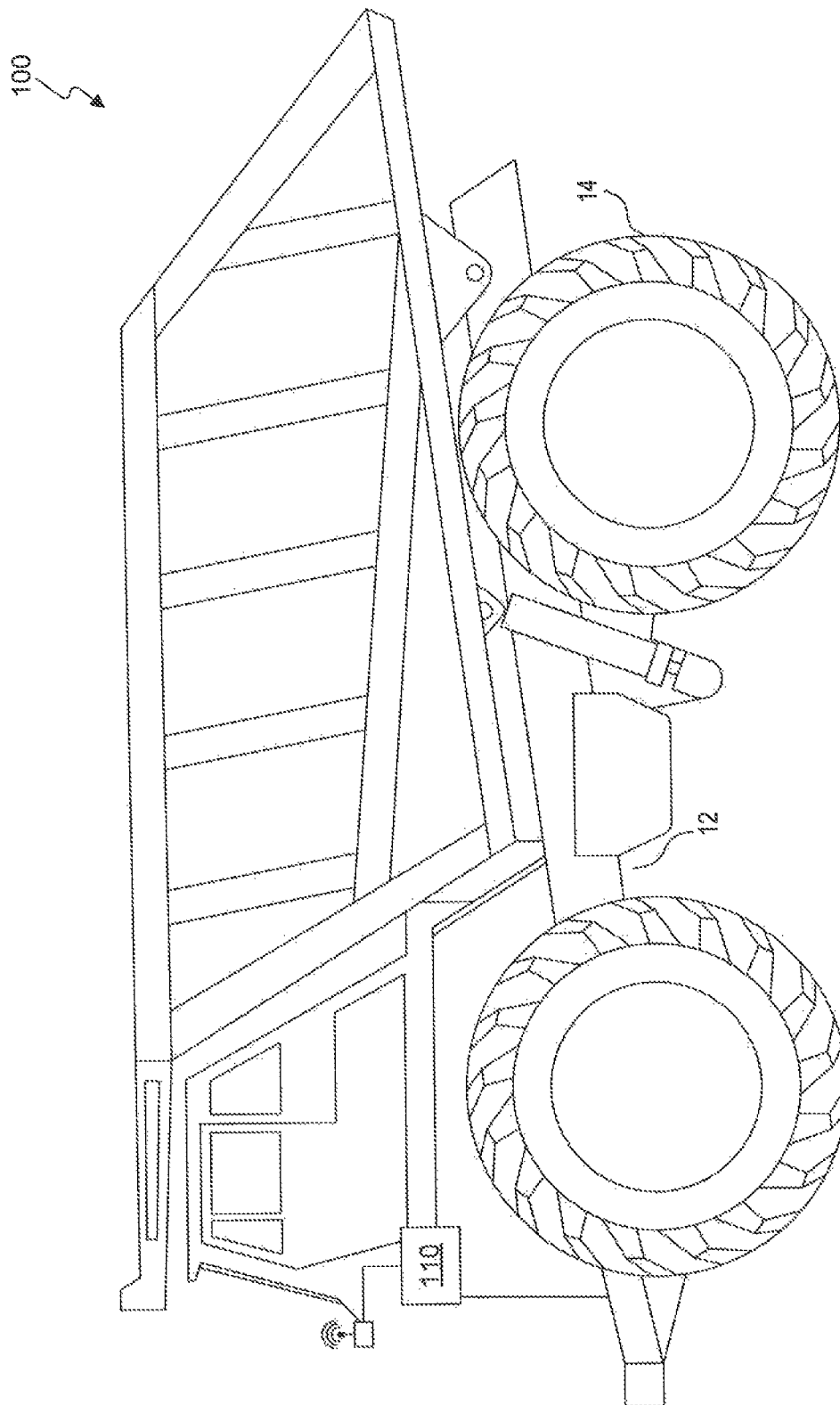
FIG. 1
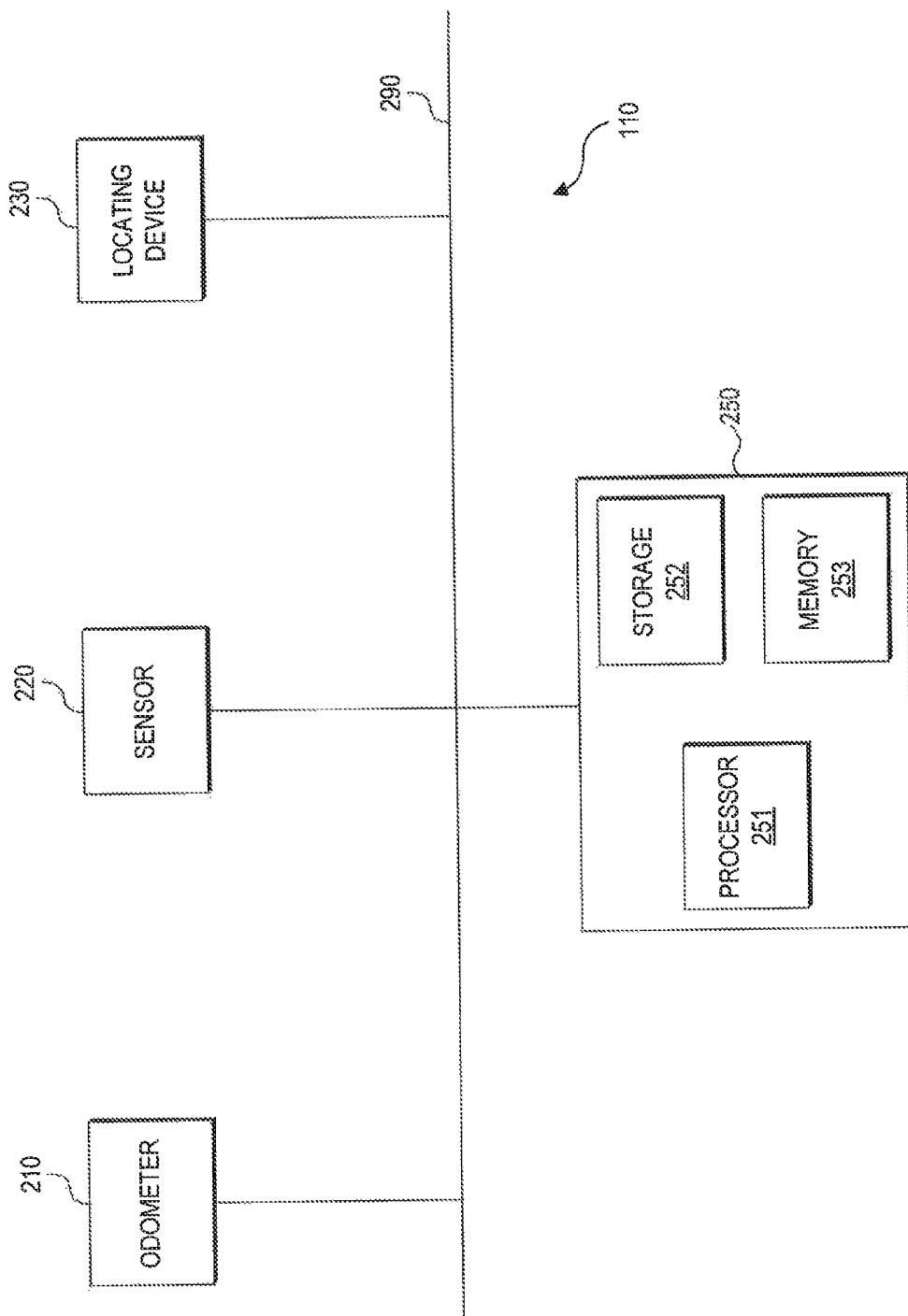
FIG. 2A
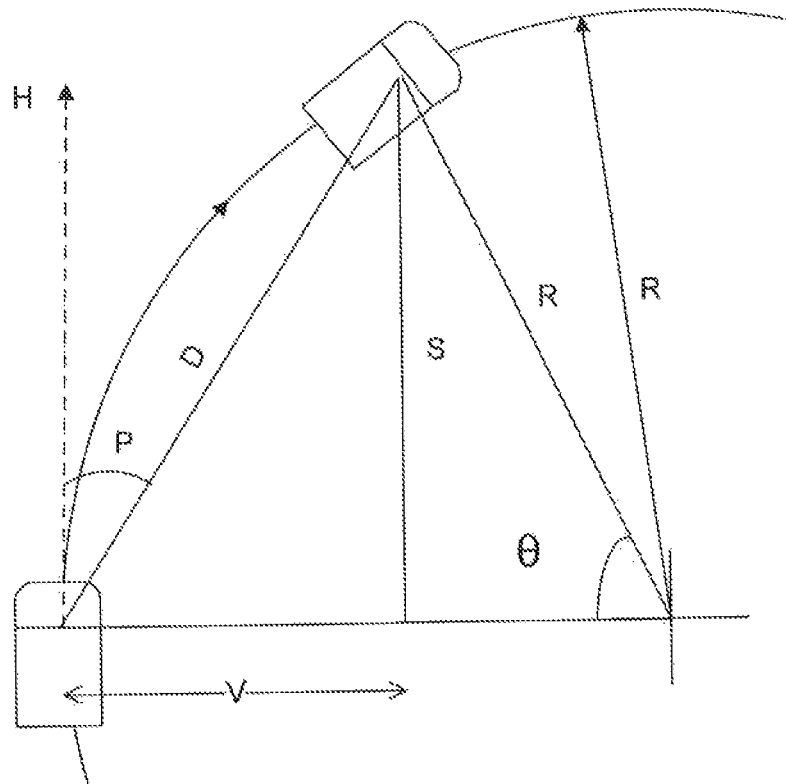
FIG. 2B
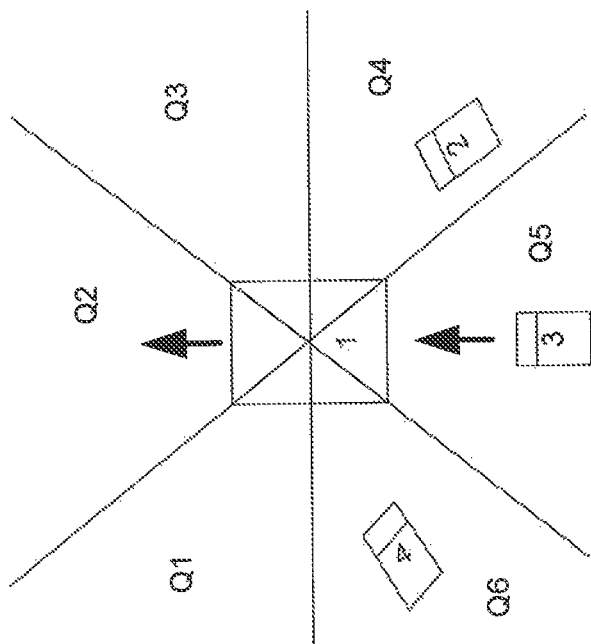
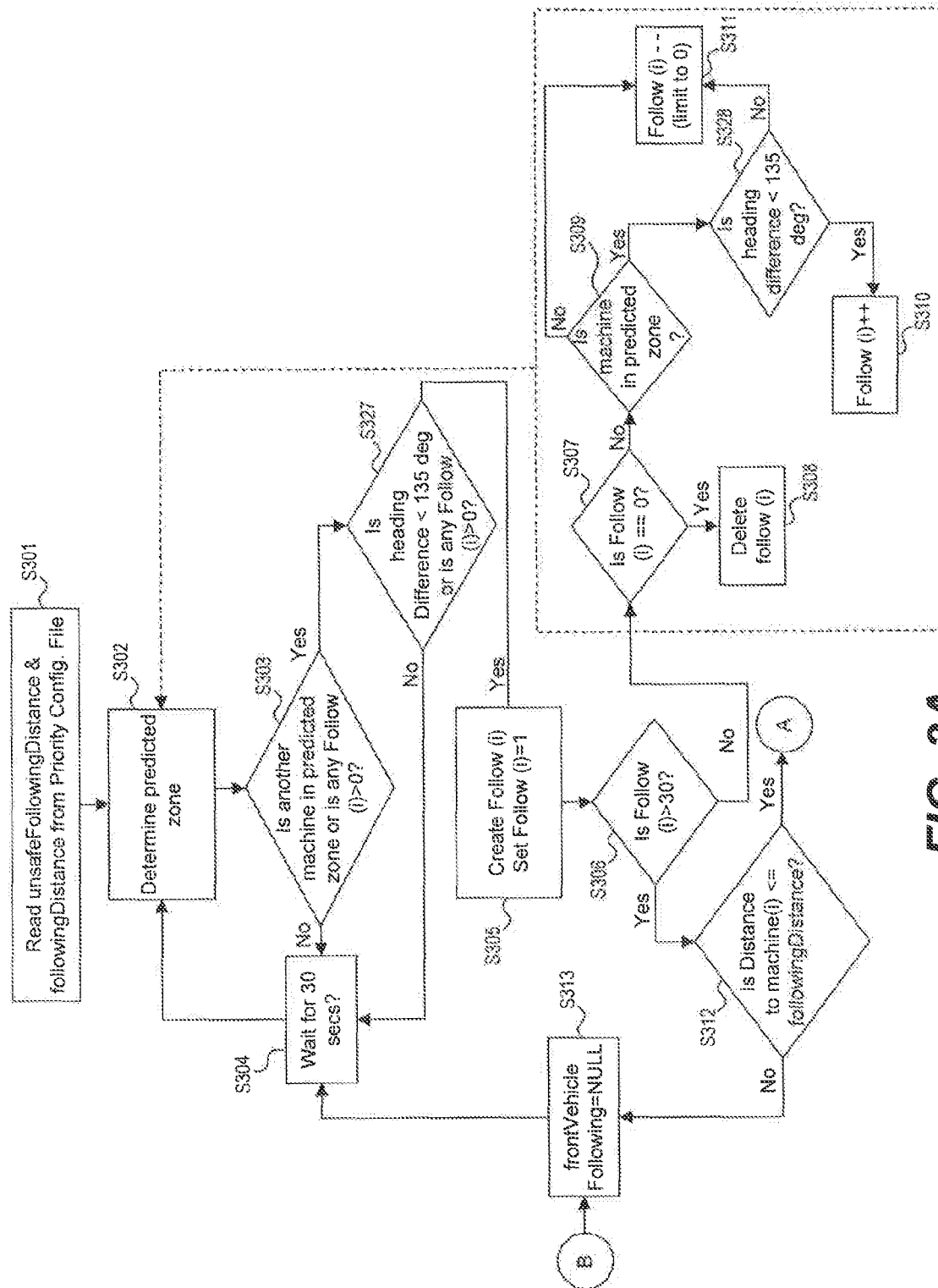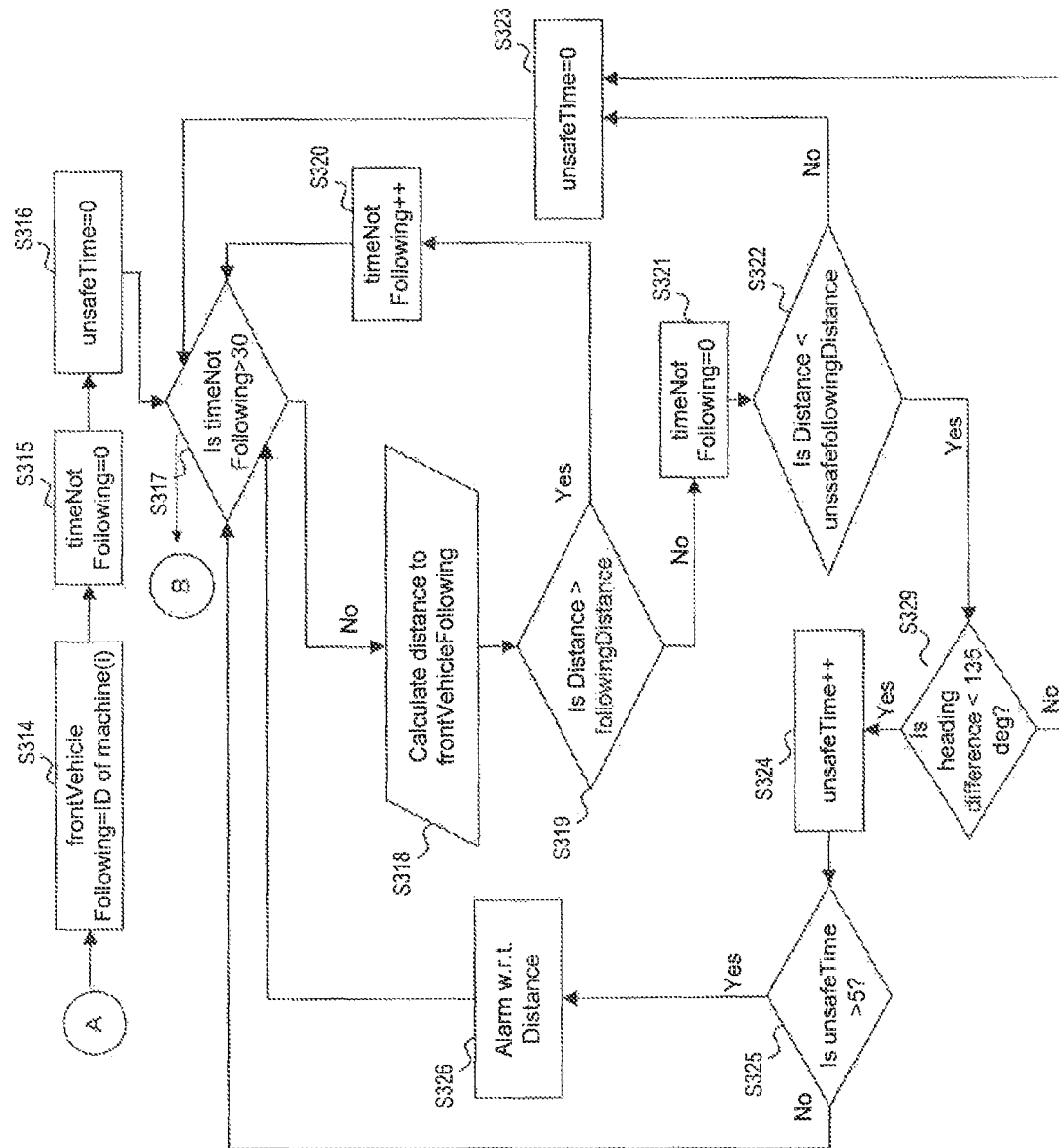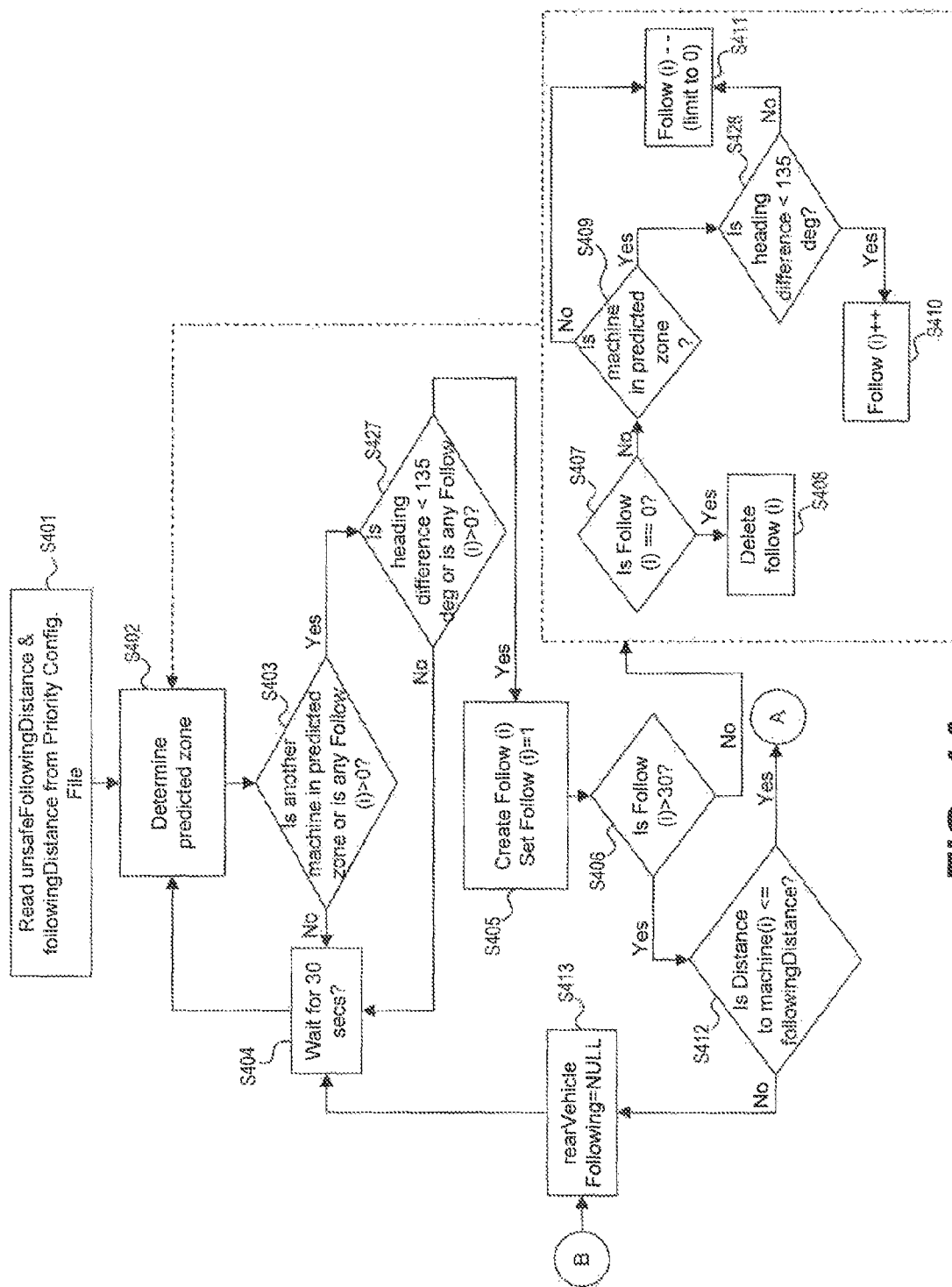*FIG. 2D*
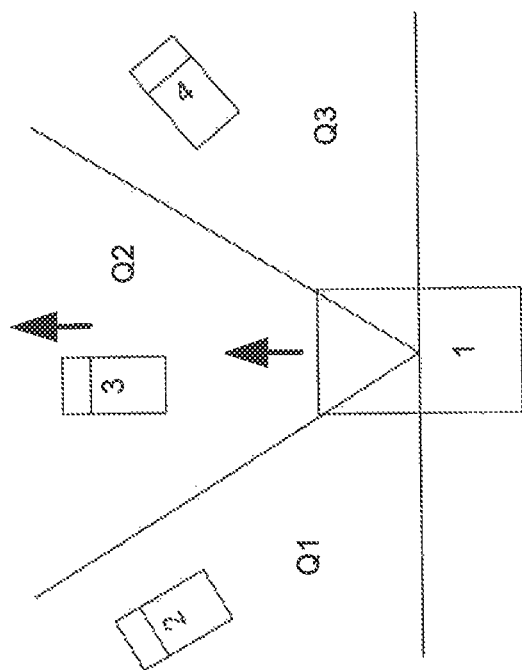
FIG. 2C

FIG. 3A
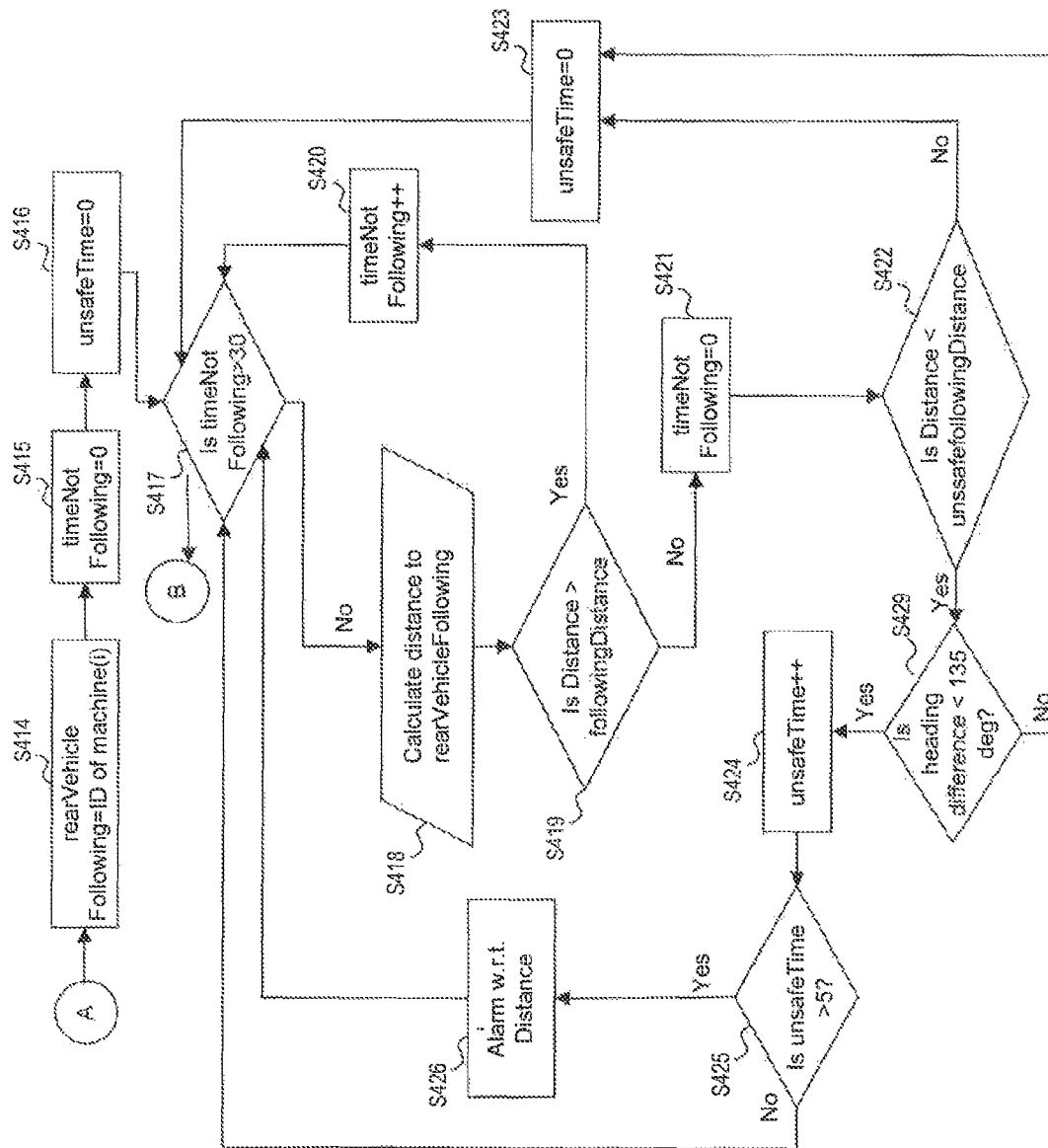
FIG. 3B

FIG. 4A

FIG. 4B

TRAFFIC ANALYSIS SYSTEM UTILIZING POSITION BASED AWARENESS

TECHNICAL FIELD

The present disclosure relates generally to a machine and, more particularly, to a machine having a traffic analysis system utilizing position based awareness.

BACKGROUND

Machines such as, for example, dozers, motor graders, wheel loaders, wheel tractor scrapers, and other types of heavy equipment are used to perform a variety of tasks. Autonomously and semi-autonomously controlled machines are capable of operating with little or no human input by relying on information received from various machine systems. For example, based on machine movement input, terrain input, and/or machine operational input, a machine can be controlled to remotely and/or automatically complete a programmed task. On minesites or other worksites, a plurality of such machines may be operated either autonomously or by vehicle operators physically present inside the machines. To increase safety on such minesites, operators of these machines need to be aware of the behavior of other machines operating around them. For example, operators of these machines need to be aware of whether or not their machine is following or is being followed by another machine and whether a safe distance exists between their machine and other machines.

An exemplary system that may be used to monitor a distance between two vehicles is disclosed in U.S. Pat. No. 5,612,686 ("the '686 patent") to Takano et al. that issued on Mar. 18, 1997. The system of the '686 patent sets predefined areas in front of a vehicle and detects whether another vehicle enters those predefined areas. If another vehicle enters the predefined areas, the system of the '686 patent initiates an alarm urging the operator to initiate a braking operation.

Although the system of the '686 patent may be useful in warning machine operators of the presence of other machines in their vicinity, the '686 patent system may not be ideal for worksites such as minesites where many machines operate simultaneously on tracks that may not be well defined. For example, the system of the '686 patent may sound an alarm to the operator as soon as another machine enters a predefined area in front of the operator's machine. Such a warning may not be required and in fact may be a nuisance because the other machine may soon leave the vicinity of the operator's machine and hence, there may not be a real collision threat. Further, the system of the '686 patent may not take into account future predicted positions of the machine in setting the predefined areas.

The traffic analysis system of the present disclosure is directed toward solving one or more of the problems set forth above and/or other problems of the prior art.

SUMMARY

In one aspect, the present disclosure is directed to a system for analyzing traffic in a vicinity of a first machine. The system may include a locating device configured to receive a signal indicative of a location of the first machine, and a controller in communication with the locating device. The controller may be configured to determine a velocity of the first machine using the received signal, and determine a projected position of the first machine based on the velocity and a yaw rate of the first machine. The controller may be further

configured to determine a predicted zone in the vicinity of the first machine based on the projected position of the first machine and determine whether a second machine is present in the predicted zone. In response to determining that the second machine is present in the predicted zone, the controller may be further configured to determine whether an unsafe condition exists between the first machine and the second machine.

In another aspect, the present disclosure is directed to a method of analyzing traffic in a vicinity of a first machine. The method may include determining, by one or more computer processors, a projected position of the first machine based on a yaw rate and velocity of the first machine. The method may further include determining, by the one or more computer processors, a predicted zone in the vicinity of the first machine based on the projected position of the first machine. The method may further include determining whether a second machine is present in the predicted zone. In response to determining that the second machine is present in the predicted zone, the method may further include determining whether an unsafe condition exists between the first machine and the second machine.

In yet another aspect, the present disclosure is directed to a non-transitory computer-readable storage device storing instruction for enabling a processor to execute a method of analyzing traffic in a vicinity of a first machine. The method may include determining a projected position of the first machine based on a yaw rate and velocity of the first machine. The method may further include determining a predicted zone in the vicinity of the first machine based on the projected position of the first machine. The method may further include determining whether a second machine is present in the predicted zone. In response to determining that the second machine is present in the predicted zone, the method may further include determining whether an unsafe condition exists between the first machine and the second machine.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial illustration of an exemplary disclosed machine;

FIG. 2A is a diagrammatic illustration of an exemplary disclosed traffic analysis system that may be used in conjunction with the machine of FIG. 1;

FIG. 2B is a diagrammatic illustration of a calculation for a prediction angle;

FIG. 2C is a diagrammatic illustration of predefined zones in front of a machine;

FIG. 2D is a diagrammatic illustration of predefined zones behind a machine;

FIGS. 3A and 3B are flowcharts depicting an exemplary disclosed method performed by the traffic analysis system of FIG. 2A when the machine is following another machine; and

FIGS. 4A and 4B are flowcharts depicting an exemplary disclosed method performed by the traffic analysis system of FIG. 2A when the machine is being followed by another machine.

DETAILED DESCRIPTION

FIG. 1 illustrates a machine 100 having an exemplary disclosed traffic analysis system 110. The machine 100 may be configured to perform some type of operation associated with an industry such as mining, construction, farming, transportation, power generation, or any other industry known in the art. For example, machine 100 may be an earth moving machine such as a haul truck, a dozer, a loader, a backhoe, an

excavator, a motor grader, a wheel tractor scraper or any other earth moving machine. Machine **100** may generally include a frame **12** that at least partially defines or supports an operator station, one or more engines mounted to the frame, a plurality of traction devices **14** driven by the engine to propel machine **100**. The traction devices **14**, in the disclosed exemplary embodiments, are wheels located at opposing sides of machine **100**. Each traction device **14** may be independently driven to turn machine **100** or simultaneously and independently driven to propel machine **100** in a straight direction. It is contemplated that one or all of traction devices **14** may be replaced with another type of traction device, if desired, such as belts or tracks.

FIG. 2A illustrates an exemplary embodiment of the traffic analysis system **110**. The traffic analysis system **110** may include an odometer **210**, a sensor **220**, a locating device **230**, and a controller **250**. The above devices and controller **250** may be connected to each other via a bus **290**. While a bus architecture is shown in FIG. 2A, any suitable architecture may be used, including any combination of wired and/or wireless networks. Additionally, such networks may be integrated into any local area network, wide area network, and/or the Internet.

Odometer **210** may provide a signal indicative of a distance traveled by machine **100**. Odometer **210** may provide as the signal, a measurement of number of rotations of the traction device **14** (such as a wheel **14**). Odometer **210** may also provide, as the signal indicative of a distance traveled by the machine, a measurement of number of rotations of a member of the machine **100**'s drive train. For example, odometer **210** may provide a measurement of number of rotations of an axle of machine **100**.

Sensor **220** may include any device capable of providing angular rates of machine **100**. For example, sensor **220** may include any device (such as a gyroscope) capable of measuring a yaw rate of the machine **100**, and producing a corresponding yaw rate signal. Sensor **220** may also include a device (such as a gyroscope) capable of measuring a pitch rate of machine **100**, and producing a corresponding pitch rate signal. Sensor **220** may further include a device (such as a gyroscope) capable of measuring a roll rate of machine **100**, and producing a corresponding roll rate signal. Exemplarily, sensor **220** may include a single IMU including 3-axis angular rate gyros that provide signals indicative of the pitch rate, yaw rate, and roll rate of machine **100**.

Locating device **230** may include any device capable of providing a signal that indicates machine **100**'s location. For example, locating device **230** could embody, a global satellite system device (e.g., a Global Positioning System (GPS) or Global Navigation Satellite System (GNSS) device), a laser range finding device, or any other known locating device that receives or determines positional information associated with machine **100** and can provide an independent measurement of the machine's position. Locating device **230** may be configured to convey a signal indicative of the received or determined positional information to one or more of interface devices for display of machine location, if desired. The signal may also be directed to a controller **250** for further processing. In the exemplary embodiments discussed herein, locating device **230** receives a GPS signal as the location signal indicative of the location of machine **100** and provides the received location signal to controller **250** for further processing. However, it will be understood by one of ordinary skill in the art that the disclosed exemplary embodiments could be modified to utilize other indicators of the location of machine **100**, if desired.

Controller **250** may include processor **251**, storage **252**, and memory **253**, included together in a single device and/or provided separately. Processor **251** may include one or more known processing devices, such as a microprocessor from the Pentium™ or Xeon™ family manufactured by Intel™, the Turion™ family manufactured by AMD™, any of various processors manufactured by Sun Microsystems, or any other type of processor. Memory **253** may include one or more storage devices configured to store information used by controller **250** to perform certain functions related to disclosed embodiments. Storage **252** may include a volatile or nonvolatile, magnetic, semiconductor, tape, optical, removable, nonremovable, or other type of storage device or computer-readable medium. Storage **252** may store programs and/or other information, such as information related to processing data received from one or more sensors, as discussed in greater detail below.

In one embodiment, memory **253** may include one or more traffic analysis programs or subprograms loaded from storage **252** or elsewhere that, when executed by processor **251**, perform various procedures, operations, or processes consistent with the disclosed embodiments. For example, memory **253** may include one or more programs that enable controller **250** to, among other things, collect data from one or more of odometer **210**, sensor **220**, and locating device **230**, process the data according to disclosed embodiments such as those embodiments discussed with regard to FIGS. 2B-4B, and analyze traffic in the vicinity of machine **100** based on the processed data.

In certain exemplary embodiments, controller **250** (and more particularly, the processor **251**) may begin executing a process of traffic analysis. Exemplarily, controller **250** may analyze traffic in front of machine **100** and behind machine **100**. Traffic in front of machine **100** may be analyzed to ensure that machine **100** ("lead machine **100**") maintains a safe distance when following another machine **100**. Traffic behind machine **100** may be analyzed to ensure that lead machine **100** maintains a safe distance from another machine **100** that may be following lead machine **100**. An example of such a traffic pattern can be seen in FIGS. 2C and 2D. In FIG. 2C, machine 1 (lead machine **100**) may be following one or more of machines 2, 3, and 4 that are in front of machine 1. In FIG. 2D, machine 1 (lead machine **100**) may be followed by one or more of machines 2, 3, and 4 that are behind machine 1. By analyzing traffic both in front and behind lead machine **100**, operators of machines 1, 2, 3, and 4 may be alerted when a safe distance between lead machine **100** and any of machines 2, 3, and 4 is breached. While the above description relates to controller **250** of machine 1 as the lead machine **100**, it will be understood that any of the other machines may be lead machines and each of their respective controllers may execute similar processes to determine safe distances between those machines and other machines. Using the traffic pattern of FIGS. 2C and 2D, traffic analysis by controller **250** of machine 1 or lead machine **100** will be explained next. At least initially, the description will focus on the traffic pattern of FIG. 2C in which lead machine **100** or machine 1 is following one or more of machines 2, 3, and 4 that are in front of machine 1.

To analyze traffic in front of lead machine **100**, controller **250** may first determine which of machines 2, 3, and 4 lead machine **100** is following or will be following on its chosen route. To determine which machines lead machine **100** is following or will be following, controller **250** may determine a projected position of lead machine **100** after a predefined time. The predefined time may be set by an operator of lead machine **100** or by someone else to any value. For example,

the predefined time may be set to 1 second, 2 seconds, 10 seconds, etc. based on the operator's preference. Once controller **250** determines the projected position of lead machine **100**, controller **250** may determine a predicted zone based on the projected position and look for other machines in the predicted zone. Exemplary zones may be predefined. For example, in FIG. **2C**, quadrants Q1, Q2, and Q3 may be zones that span 60 degrees each and may be predefined relative to the current heading of lead machine **100** (machine 1). The predicted zone for lead machine **100** may be the quadrant in which the projected position of lead machine **100** falls. For example, if the projected position of machine 1 falls in Q3, Q3 may be the predicted zone in which controller **250** looks for other machines. As shown in FIG. **2C**, machine 4 is in Q3 and may be a machine that is being followed by lead machine **100** if the projected position of lead machine **100** falls in Q3. Once a machine (for example, machine 4) has been found to be in lead machine **100**'s predicted zone, controller **250** may determine whether machine 4 remains in lead machine **100**'s predicted zone for a certain period of time. It will be noted that the predicted zone for lead machine **100** may continuously change or update as lead machine **100** moves along its route. If machine 4 remains in lead machine **100**'s predicted zone for a certain period of time, lead machine **100** may be deemed to be following machine 4. At this time, controller **250** may begin to analyze whether an unsafe condition exists between lead machine **100** and machine 4. For example, controller **250** may determine whether a distance between lead machine **100** and machine 4 is less than a predefined unsafe following distance and alert the operators of lead machine **100** and machine 4 if such distance is breached. Next, a detailed description of the above traffic analysis is provided beginning with the calculation of the projected position and predicted zone.

The calculation of the projected position and predicted zone will be described with reference to FIGS. **2B-2D**. To predict the position of lead machine **100** after a predefined time ("t"), controller **250** may first determine a heading of the lead machine **100**. Heading is the angle lead machine **100** is pointed relative to North. The heading may be determined by controller **250** by integrating a yaw rate signal received from sensor **220**. Alternatively, the heading may be calculated using GPS signals that may be received from locating device **230**. For example, heading may be calculated using GPS signals using the following equation:

$$\text{Heading} = a\tan([E-E(z-1)]/[N-N(z^{-1})]) \tag{1}$$

Where N is Northing, E is Easting, and z^{-1} is a unit delay. It should be noted that trigonometric functions typically provide the results in radians. In order to convert the result to degrees, the heading obtained from equation 1 may be multiplied by $180/\pi$.

Using the heading, controller **250** may determine the yaw rate of lead machine **100**. In certain exemplary embodiments, the yaw rate may be directly available from sensor **220**. In other exemplary embodiments, the yaw rate may be calculated using the heading obtained from equation 1. For example, the following equation may be used to calculate yaw rate:

$$\text{Yaw Rate} = (\text{Heading} - \text{Heading}(z^{-1}))/(\Delta t) \tag{2}$$

Where z^{-1} is a unit delay and Δt is the change in time between the two heading readings.

Next, a radius of travel (R) illustrated in FIG. **2B** may be calculated by controller **250**. The radius of travel is the radius of the arc lead machine **100** is traveling on. This radius is a function of the yaw rate and the velocity of lead machine **100**.

The velocity of lead machine **100** may be calculated using readings from odometer **210** or by using GPS signals from locating device **230** or by another means. The radius of travel may be greater than +/−50 meters in some exemplary embodiments or may be limited to some other minimum or maximum value (for example, minimum +/−50 meters) based on the site controller's preference. The radius of travel may be calculated using the following equation:

$$\text{Radius of Travel [m]} = 360 \text{ [deg]} \times (1/\text{Yaw Rate})[\text{sec}/\text{deg}] \times \text{velocity [m/s]} \times 1/(2\pi) \tag{3}$$

Next, a predicted distance traveled for lead machine **100** may be calculated by controller **250** by multiplying the velocity with a predefined projection time. The predefined projection time represents how far in the future you want to know the lead machine **100**'s position. For example, the predefined projection time may be 1 second, 2 seconds, 10 seconds, etc. The predicted distance traveled is a prediction of how far lead machine **100** will travel from its current position in the predefined projection time at its current velocity. The predicted distance traveled can also be thought of as the straight line distance between the projected position and the current position for lead machine **100**. The predicted distance traveled is illustrated in FIG. **2B** as "D."

Next, a chord angle (θ) illustrated in FIG. **2B** may be calculated using the following equation

$$\theta[\text{rad}] = \text{Predicted Distance Traveled [m]}/\text{Radius of Travel}(R)[\text{m}] \tag{4}$$

The projected position of lead machine **100** relative to its current position may now be calculated using the following equations:

$$V\text{ [m]} = R\text{ [m]} \times (1 - \cos(\theta)) \tag{5}$$

$$S\text{ [m]} = R\text{ [m]} \times \sin(\theta) \tag{6}$$

It will be noted that 0 may be converted to degrees prior to using it in equations 5 and 6 in some exemplary embodiments depending on the type of trigonometric calculator employed by controller **250**.

Next, a predicted angle (P) may be calculated by controller **250** that is an angle of the projected position of lead machine **100** relative to a current heading direction of lead machine **100** that is denoted by "H" in FIG. **2B**. The predicted angle may be calculated using the following equation:

$$P[\text{deg}] = a\tan(V/S) * \text{sign of Yaw Rate} \tag{7}$$

The sign of Yaw Rate may be positive if lead machine **100** is turning right and negative is it is turning left.

By using the predicted angle, controller **250** may identify the predicted zone for lead machine **100** from among Q1, Q2, and Q3. For example, if P is between +30 degrees and −30 degrees, the predicted zone may be Q2. If P is greater than +30 but less than +90, the predicted zone may be Q3. If P is less than −30 but greater than −90 degrees, the predicted zone may be Q1. It will be noted that if the zones were defined differently, i.e., not spanning 60 degrees each, values of P will correspond differently to the predicted zones. For example, if each of the zones spanned 90 degrees, then −90<P<0 degrees may correspond to one predicted zone and 0>P>90 may correspond to another predicted zone. It will further be noted that the size of the predicted zone may be limited by defining the maximum radius for the circle of which the predicted zone is a segment.

After selecting a predicted zone, controller **250** may determine if another machine **100** (for example, machines 2, 3, or 4) is in the predicted zone. Controller **250** may make this determination by obtaining a location (for example, GPS

coordinates) of the different machines and checking if any of the GPS coordinates are within the predicted zone. For example, if the predicted zone or quadrant of interest happens to be Q3, controller **250** may determine that machine 4 is in the predicted zone of lead machine **100**.

Next, controller **250** may determine whether lead machine **100** is following a machine in its predicted zone, which in this example happens to be machine 4. To determine whether lead machine **100** is following machine 4, controller **250** may execute a loop and initialize a counter (Follow (4), where 4 refers to the machine id) for machine 4. Exemplarily, Follow (4) may be initialized to 1. After incrementing Follow (4), controller **250** may recalculate the predicted zone because lead machine **100** may have moved to a new position. If machine 4 is present in the predicted zone, Follow (4) may be further incremented. The loop may continue executing until Follow (4) exceeds some preset threshold value. If Follow (4) exceeds the preset threshold value, lead machine **100** may be deemed to be following machine 4 if the distance between machine 4 and lead machine **100** is less than a predefined Following Distance value. If the distance between lead machine **100** and machine 4 exceeds the predefined Following Distance value, lead machine **100** may not be considered to be following machine 4, and the algorithm may start from the beginning. When the algorithm starts from the beginning, each of the counters (for example, Follow (4)) may be deleted or reset. Exemplarily, controller **250** may determine the distance between the primary machine (here, lead machine **100**) and the machine that it is following (here, machine 4) by a variety of means. For example, controller **250** may utilize GPS coordinates for both machines to determine the distance. In other embodiments, controller **250** may utilize a radar-based system or laser-based system to determine the distance between lead machine **100** and machine 4. By requiring Follow (4) to exceed a preset threshold value, controller **250** may ensure that lead machine **100** is deemed to be following machine 4 only after machine 4 has remained in lead machine **100**'s predicted zone for some minimum time. It will be noted that more than one machine may be present in lead machine **100**'s predicted zone and separate counters may be created for each machine. For example, if machine 3 was also in lead machine **100**'s predicted zone, a Follow (3) may be created by controller **250** in addition for Follow (4).

Once lead machine **100** is determined to be following machine 4, controller **250** may determine whether an unsafe condition exists between lead machine **100** and machine 4. If the distance between lead machine **100** and machine 4 is less than a predefined unsafe Following Distance, controller **250** may alert the operators and mine site supervisors that an unsafe following situation has been created and may continue to alert until the operator of the primary machine (here, lead machine **100**) or the other machines takes corrective action to move the machines to a safe following distance.

While the above operation was described with reference to machines in front of lead machine **100**, controller **250** may also determine whether any machines that are behind lead machine **100** are within an unsafe distance from itself. A majority of the process implemented by controller **250** for machines behind it is identical to the process for machines in front of lead machine **100**. A difference, however, is the predicted zone. For machines behind lead machine **100**, controller **250** may determine its predicted zone to be a zone that is 180 degrees reversed from the predicted zone in front of lead machine **100**. For example, if controller **250** determines Q3 (see FIG. 2D) as the predicted zone in front of the machine based on the predicted angle (P) calculation in equation 7, controller **250** may determine Q6 as the predicted zone

behind lead machine **100**. Based on the exemplary traffic pattern illustrated in FIG. 2D, if controller **250** determines that Q6 is a predicted zone, controller **250** may then determine whether machine 4 is following lead machine **100** and whether a safe distance is present between the two machines.

FIGS. **3A-4B** illustrate exemplary processes implemented by the controller **250** that describe in further detail the above traffic analysis operation. A detailed description of FIGS. **3A-4B** is provided in the next section.

INDUSTRIAL APPLICABILITY

The disclosed traffic analysis system **110** may be applicable to any machine where machine safety on worksites is desired. The disclosed traffic analysis system **110** may provide for improved detection of existence of an unsafe condition between two machines and may alert the operators and mine site supervisors of the unsafe condition. FIGS. **3A-3B** illustrate an algorithm that may be executed by controller **250** of lead machine **100** to determine whether an unsafe condition exists between lead machine **100** and another machine in front of lead machine **100**. Similarly, FIGS. **4A-4B** illustrate an algorithm that may be executed by controller **250** of lead machine **100** to determine whether an unsafe condition exists between lead machine **100** and another machine behind lead machine **100**. Operation of the traffic analysis system **110** will now be described in connection with the flowchart of FIGS. **3A-3B**.

In step **301**, controller **250** may read certain parameters from a priority configuration file that may be stored in storage **252** or memory **253** or elsewhere. For example, controller **250** may read parameters such as Following Distance and unsafe Following Distance that may be utilized later in the algorithm. In step **302**, controller **250** may determine a predicted zone. As explained earlier, to determine the predicted zone, controller **250** may determine the projected position of lead machine **100** after a predefined time ("t") and by further utilizing equations (1)-(7), controller **250** may determine a predicted angle ("P") which is an angle of the projected position of lead machine **100** relative to a current heading direction (denoted by "H" in FIG. 2B) of lead machine **100**.

By using the predicted angle P, controller **250** may identify the predicted zone for lead machine **100** from among predefined zones in front of lead machine **100**. Exemplarily, as shown in FIG. 2C, the predefined zones may be Q1, Q2, and Q3 each of which span 60 degrees. If P is between +30 degrees and −30 degrees, the predicted zone may be determined to be Q2. If P is greater than +30 but less than +90, the predicted zone may be determined to be Q3. If P is less than −30 but greater than −90 degrees, the predicted zone may be determined to be Q1. It will be noted that if the zones were defined differently, i.e., not spanning 60 degrees each, values of P will correspond differently to the predicted zones. For example, if each of the zones spanned 90 degrees, then −90<P<0 degrees may correspond to one predicted zone and 0>P>90 may correspond to another predicted zone. It will further be noted that the size of the predicted zone may be limited by defining the maximum radius for the circle of which the predicted zone is a segment.

After selecting a predicted zone, controller **250** may determine in S**303** if another machine **100** (for example, machines **2**, **3**, or **4**) is in the predicted zone or if Follow (i) (which is a parameter described later) for any machine is greater than 0. Controller **250** may make this determination by obtaining a location (for example, GPS coordinates) of the different machines and checking if any of the GPS coordinates are within the predicted zone. For example, if the predicted zone

or quadrant of interest happens to be Q3, controller **250** may determine that machine 4 is in the predicted zone of lead machine **100**. However, if no machine other than lead machine **100** is present in the selected predicted zone and no Follow (i) exists that is greater than 0, controller **250** may proceed to S304 and wait for a predefined time (for example, 30 seconds) before returning to S302 to determine a new predicted zone.

If controller **250** determines in S303 that another machine (for example, machine **4**) is in its predicted zone or determines that a Follow (i) exists for some machine that is not greater than zero, controller **250** may next determine whether lead machine **100** is following machine 4. However, prior to determining whether lead machine **100** is following machine 4, controller **250** may determine in S327 whether a heading difference between lead machine **100** and machine 4 is less than 135 degrees or if Follow (i) for any machine is greater than 0. If the heading difference is determined to be more than 135 degrees, controller **250** may determine that lead machine **100** is not following machine 4 because the lead machine **100** and machine 4 will likely cross each other as they are traveling in almost opposite directions. In such a case, controller **250** may proceed to S304 and wait for a predefined time before determining an updated predicted zone, when no Follow (i) is greater than 0 for any machine. If in S327 controller **250** determines that the heading difference between lead machine **100** and machine 4 is less than 135 degrees or determines that a Follow(i) exists for some machine that is greater than 0, controller **250** may proceed to S305 and initialize a counter Follow (i) for machine (i). As machine 4 is in the predicted zone, controller **250** may create and initialize Follow (4), where 4 refers to the machine id for machine 4. Exemplarily, Follow (4) may be initialized to 1.

Next, in S306, controller **250** may determine whether Follow (i) (here, Follow (4)) is greater than some preset threshold value. Exemplarily, the preset threshold value may be set to but the mine site operator may set any suitable number. If Follow (4) is not greater than 30, controller **250** may determine that machine 4 has not been in lead machine **100**'s predicted zone for long enough and so cannot yet be deemed as being followed by machine 4. If Follow (4) is not greater than 30 in S306, controller **250** may enter into a sub routine denoted by dotted lines in FIG. **3A**. The sub routine (S307-S311) may execute for each machine for which a Follow (i) exists. So, for example, if at time t1 machine 3 entered lead machine **100**'s predicted zone, a Follow (3) may have been created by controller **250**. If at a later time t2 or at the same time t1, if machine 4 entered lead machine **100**'s predicted zone, a Follow (4) may be created. When controller **250** enters the subroutine, it may execute the subroutine for each of the Follow (i)s.

Inside the subroutine, controller **250** may check whether Follow (i) (for example, Follow (4) and Follow (3) if both have been previously created) is equal to 0 in S307. Taking the example of Follow (4), if Follow (4) is equal to 0, this would mean that machine 4 is no longer in lead machine **100**'s predicted zone and controller **250** may proceed to S308 to delete Follow (4). However, if in S307, controller **250** determines that Follow (4) is not equal to 0, controller **250** may proceed to S309 to determine whether machine 4 is in lead machine **100**'s predicted zone as determined in S302. If in S309, controller **250** determines that machine 4 is in the predicted zone, controller **250** may check in S328 whether the heading difference between machine 4 and lead machine **100** is less than 135 degrees. If the heading difference is less than 135 degrees, Follow (4) may be incremented in S310 else Follow (4) may be decremented in S311. If in S309, controller

250 determines that machine 4 is not in the predicted zone, Follow (4) may be decremented in S311. After the subroutine has executed for existing Follow (i)'s, control may return to S302 where controller **250** may recalculate the predicted zone because lead machine **100** may have moved to a new position.

If in S306, controller **250** determines that for one of the machines, Follow (i) (for example, Follow (4)) exceeds the preset threshold value (for example, 30), controller **250** may proceed to S312. In S312, controller **250** may obtain the Following Distance parameter from the configuration file and determine whether a distance between lead machine **100** and machine 4 is less than the predefined Following Distance. The value Following Distance may be set to be greater than unsafe Following Distance and may act as a preliminary check for a safe distance between the two machines. For example, Following Distance may be set to a value such as 100 m and unsafe Following Distance may be set to 20 m. It will be noted that any suitable value may be set for these parameters. If in S312, controller **250** determines that the distance between machine 4 and lead machine **100** is greater than Following Distance, controller **250** may proceed to S313 and set a value front Vehicle Following to Null which indicates that lead machine **100** is not following another machine. It will be noted that if in S306, Follow (i) is greater than 30 for more than one machine, the distance to the closest machine may be selected as the distance for purposes of S312. If in S312, controller **250** determines that the distance between machine 4 (assuming machine 4 is the closest machine) and lead machine **100** is less than Following Distance, controller **250** may determine that lead machine **100** is following machine 4. Accordingly, in S314, controller **250** may set a parameter front Vehicle Following equal to the id of machine 4. In S315 and S316, controller **250** may initialize variable time Not Following and unsafe Time equal to 0.

In S317, controller **250** may check whether time Not Following is greater than some preset threshold value (for example, 30). This check is to make sure that if lead machine **100**, which was deemed to be following machine 4, is maintaining a distance from machine that is greater than Following Distance for a given amount of time, then lead machine **100** should not be deemed as following machine 4. Accordingly, if in S317, controller **250** determines that time Not Following is greater than 30, control may proceed to S313. Otherwise, control may proceed to S318 where controller **250** may calculate the distance between lead machine **100** and machine 4. In S319, controller **250** may check whether the distance is greater than Following Distance and if yes, the parameter time NOT Following may be incremented in S320. Otherwise, time Not Following may be set to 0 in S321 and controller **250** may proceed to S322. In S322, controller **250** may check whether the distance between lead machine **100** and machine 4 is less than unsafe Following Distance and if yes, control may proceed to S329 where controller **250** may check whether the heading difference between lead machine **100** and machine 4 is less than 135 degrees. If the heading difference is less than 135 degrees, the counter unsafe Time may be incremented else unsafe Time may be set to 0 in S323. If in S322, controller **250** determines that the distance between lead machine **100** and machine 4 is greater than unsafe Following Distance, unsafe Time may be set to 0 in S323.

After incrementing unsafe Time in S324, controller **250** may check whether unsafe Time is less than a preset threshold (for example, 5). If unsafe Time is less than the preset threshold, control may proceed back to S317 else controller **250** may determine that an unsafe distance has been maintained between lead machine **100** and machine 4 for some time and alerts the operators of lead machine **100** and machine 4. It will

be noted that the various values (for example, 135 degrees heading difference, unsafe Time of 5, etc.) that have been indicated in the above algorithm are only examples and that any appropriate value may be set by the operator for these different parameters. The process may continue to repeat in this manner until receiving instructions to stop or until new data ceases to be collected from the machine 100.

While the above algorithm was described with reference to machines in front of lead machine 100, controller 250 may also determine whether any machines that are following lead machine 100 are within an unsafe distance from itself. Exemplarily, to determine whether any machines that are following lead machine 100 are within an unsafe distance from itself, controller 250 may execute the algorithm described with reference to FIGS. 4A-4B. A majority of the algorithm of FIGS. 4A-4B is identical to the algorithm described with reference to FIGS. 3A-3B. For example, S301 in FIG. 3A is identical to S401 in FIG. 4A. Accordingly, only the differences between the two algorithms are described. A difference between the two algorithms is the predicted zone determined in S302 and S402. For machines behind lead machine 100, controller 250 may determine its predicted zone to be a quadrant that is 180 degrees reversed from the predicted zone in front of lead machine 100. For example, if controller 250 determines Q3 (see FIG. 2D) as the predicted zone in front of the machine based on the predicted angle (P) calculation in equation 7, controller 250 may determine Q6 as the predicted zone behind lead machine 100 in S402. Based on the exemplary traffic pattern illustrated in FIG. 2D, if controller 250 determines that Q6 is the predicted zone, controller 250 may then determine whether machine 4 is following lead machine 100 and whether a safe distance is present between the two machines. Another difference is that in S414, the id of the machine that is following lead machine 100 may be set for the parameter rear Vehicle Following and in S413, rear Vehicle Following may be set to Null.

The disclosed exemplary embodiments may allow for improved detection of existence of an unsafe condition between two machines and may alert the operators and mine site supervisors of the unsafe condition. For example, by creating multiple counters and checking whether the counters exceed preset threshold value, the system raises alarms about unsafe conditions only after existence of the unsafe condition has been observed over some period of time. This decreases the number of false alarms that may be initiated by prior art systems.

It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed traffic analysis system. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed traffic analysis system. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

What is claimed is:

1. A computer-implemented method of analyzing traffic in a vicinity of a first machine, comprising:
   determining a predicted distance traveled for the first machine based on velocity of the first machine and a predefined time;
   determining, by one or more computer processors, a projected position of the first machine based on the predicted distance traveled and a yaw rate of the first machine;
   determining, by the one or more computer processors, an angle of the projected position relative to a current heading of the first machine;

   selecting, by the one or more computer processors, a predicted zone from among a plurality of predefined zones in the vicinity of the first machine based on the determined angle;
   determining whether a second machine is present in the predicted zone; and
   in response to determining that the second machine is present in the predicted zone, determining whether an unsafe condition exists between the first machine and the second machine.

2. The computer-implemented method of claim 1, wherein determining the projected position includes:
   determining a radius of travel for the first machine based on the yaw rate and the velocity; and
   determining the projected position using the radius of travel and the predicted distance traveled.

3. The computer-implemented method of claim 1, wherein determining whether an unsafe condition exists includes:
   determining whether the second machine is following or is being followed by the machine; and
   in response to determining that the second machine is following or is being followed by the first machine, determining a distance between the first machine and the second machine.

4. The computer-implemented method of claim 3, wherein determining whether the second machine is following or is being followed by the first machine includes:
   initializing a first counter for the second machine;
   updating the projected position of the first machine;
   updating the predicted zone based on the updated projected position; and
   incrementing the first counter when the second machine is present in the updated predicted zone.

5. The computer-implemented method of claim 4, wherein the second machine is determined to be following or being followed by the first machine when the first counter exceeds a first predefined threshold value.

6. The computer-implemented method of claim 3, wherein determining whether an unsafe condition exists further includes:
   executing a loop that checks whether the distance is less than a predefined unsafe following distance and increments a second counter when the distance is less than the predefined unsafe following distance; and
   determining that an unsafe condition exists when the second counter exceeds a second predefined threshold value.

7. A system for analyzing traffic in a vicinity of a first machine, comprising:
   a locating device configured to receive a signal indicative of a location of the first machine; and
   a controller in communication with the locating device, the controller configured to:
   determine a velocity of the first machine using the received signal;
   determine a predicted distance traveled for the first machine based on the velocity and a predefined time;
   determine a projected position of the first machine based on the predicted distance traveled and a yaw rate of the first machine;
   determine an angle of the projected position relative to a current heading of the first machine;
   selecting a predicted zone from among a plurality of predefined zones in the vicinity of the first machine based on the determined angle;
   determine whether a second machine is present in the predicted zone; and

in response to determining that the second machine is present in the predicted zone, determine whether an unsafe condition exists between the first machine and the second machine.

8. The system of claim **7**, wherein the controller is configured to determine the projected position by:

determining a radius of travel for the first machine based on the yaw rate and the velocity; and

determining the projected position using the radius of travel and the predicted distance traveled.

9. The system of claim **7**, wherein the controller is configured to determine whether an unsafe condition exists by:

determining whether the second machine is following or is being followed by the first machine; and

in response to determining that the second machine is following or is being followed by the first machine, determining a distance between the first machine and the second machine.

10. The system of claim **9**, wherein the controller is configured to determine whether the second machine is following or is being followed by the machine by:

initializing a first counter for the second machine;

updating the projected position of the first machine;

updating the predicted zone based on the updated projected position; and

incrementing the first counter when the second machine is present in the updated predicted zone.

11. The system of claim **10**, wherein the second machine is determined to be following or being followed by the first machine when the first counter exceeds a first predefined threshold value.

12. The system of claim **9**, wherein to determine whether an unsafe condition exists the controller is further configured to:

execute a loop that checks whether the distance is less than a predefined unsafe following distance and increments a second counter when the distance is less than the predefined unsafe following distance; and

determine that an unsafe condition exists when the second counter exceeds a second predefined threshold value.

13. A non-transitory computer-readable storage medium storing instructions for enabling a processor to execute a method of analyzing traffic in a vicinity of a first machine, the method comprising:

determining a predicted distance traveled for the first machine based on a velocity of the first machine and a predefined time;

determining a projected position of the first machine based on the predicted distance traveled and a yaw rate of the first machine;

determining an angle of the projected position relative to a current heading of the first machine;

selecting a predicted zone from among a plurality of predefined zones in the vicinity of the machine based on the determined angle;

determining whether a second machine is present in the predicted zone; and

in response to determining that the second machine is present in the predicted zone, determining whether an unsafe condition exists between the first machine and the second machine.

14. The non-transitory computer-readable storage medium of claim **13**, wherein determining the projected position includes:

determining a radius of travel for the first machine based on the yaw rate and the velocity; and

determining the projected position using the radius of travel and the predicted distance traveled.

15. The non-transitory computer-readable storage medium of claim **13**, wherein determining whether an unsafe condition exists includes:

determining whether the second machine is following or is being followed by the machine; and

in response to determining that the second machine is following or is being followed by the first machine, determining a distance between the first machine and the second machine.

16. The non-transitory computer-readable storage medium of claim **15**, wherein determining whether the second machine is following or is being followed by the first machine includes:

initializing a first counter for the second machine;

updating the projected position of the first machine;

updating the predicted zone based on the updated projected position; and

incrementing the first counter when the second machine is present in the updated predicted zone.

17. The non-transitory computer-readable storage medium of claim **16**, wherein the second machine is determined to be following or being followed by the first machine when the first counter exceeds a first predefined threshold value.

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.   : 9,200,904 B2
APPLICATION NO.   : 13/837905
DATED   : December 1, 2015
INVENTOR(S)   : Borland et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page item [73], delete "Caterpillar," and insert -- Caterpillar Inc., --.

Signed and Sealed this
Twenty-fifth Day of October, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office